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HISTORY OF THE GAS TURBINE ENGINE IN THE UNITED STATES: BIBLIOGRAPHY

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This technical report has been reviewed and is approved for publication.

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A Bibliography of aircraft gas turbine engine sources has been assembled for use in research of the book History of the Aircraft Gas Turbine Engine in the United States. The bibliography consists of sources found in research conducted at Air Force, Navy, Army, NASA, industry, museum, and technical society facilities. The sources identified are bibliographies, books, reports, theses, articles, and technical papers written for presentation. This bibliography also includes research criteria, search methodology, task schedules, and an outline for the content of the book, History of the Aircraft Gas Turbine Engine in the United States.

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1. INTRODUCTION

The Aircraft Gas Turbine Engine (AGTE) has developed into one of the key technological achievements of the twentieth century. Its development has revolutionalized travel. Along with television, the computer, and the unlocking of the secrets of the atom, the turbojet has lent its name to an age -- the "jet age." But what do we know of its development?

Ask any American sixth-grade child who invented the lightbulb and they will tell you it was Thomas Edison. But ask them who invented the first two jet engines to fly, and they would not know. British schoolchildren can probably tell you who the first inventor of the aircraft jet engine was -- Sir Frank Whittle, but then again, the British have always been more attentive to their own history than we Americans have been to ours. Millions of people have flown in turbojet, turboshaft, and turboprop-driven aircraft, but few of those people would recognize the names of Dr. Hans von Ohain, Sir Frank Whittle, Dr. Anselm Franz, William "Bill" Brown, Gerhard Neumann, or other turbojet pioneers who have worked to make the AGTE the technological marvel that it is today.

Although there have been excellent books published on reciprocating aircraft engines developed in the United States, and despite the publication of the Origins of the Turbojet Revolution, by Edward Constant III, very little has been written to relate and analyze the development of the aircraft gas turbine engine in this country. The AGTE has undergone tremendous growth and development, both in the United Stated and overseas. There have been remarkable advances in the technology and application of the turbojet engines pioneered by von Ohain and Whittle. This growth in the technology has been accompanied by a corresponding dramatic increase in cost and complexity. The turbojet community described by Constant has grown from a handful of people working in Germany and Britain to large multi-billion dollar establishments in over twenty countries. Where is the history of these accomplishments?

Lest the reader gain the impression that there has been no history written at all on the AGTE, let me assure you that there has. There has been much written on the origins and pioneering work on the early AGTEs. There has been some good history and bad history produced by individual companies on their AGTE development. An exhaustive amount of primary historical material consisting of Government contract documentation has been generated. An equally overwhelming amount of secondary source material consisting of periodical articles have been published. The aviation industry is one of the most closely watched industries today, with dozens of publications devoted to watching the activities of both the Government and industry. A great deal of continuing research will be devoted to sorting out the historical "wheat" from the mass of published and unpublished "chaff" of material. This bibliography on AGTE development in the United Stated is a first step in that direction.

The mass of published and unpublished material is vital to our understanding of the technology of the AGTE and its impact on our society. But we must not neglect the human side of the equation. The real story of the aircraft gas turbine engine is that of the people who at first nursed the technology along, searching for just the right combination of materials and design that would enable them to unlock the secret to turbojet flight. That story continues through wars and hardship to development and utilization of the turbojet as a weapon of war, then through cold war, detente, confrontation, and glasnost. These people constantly pushed turbojet technology to its limits, exploring new uses for the turbojet on land and sea, and scaling the technology both larger and smaller to push the limits of aerodynamics and thermodynamics farther and farther. We are fortunate that many of those turbojet pioneers are still alive to help us tell their stories. But their numbers are dwindling fast.

This constitutes the final report for Task 13 of contract F33615-65-C-2575, entitled, Scholarly Research in Aircraft Turbine Engines, for the Air Force Aero Propulsion and Power Laboratory. There are two major parts to this report. The first part is a Historical Sources Survey of the AGTE. In this portion of the Final Report, I will discuss my research methodology, bibliographic search criteria, oral history source criteria, and I will list the bibliographic sources found during the performance portion of this Task. Each type of bibliographic source will be listed separately.

The second part is a proposed outline of a book to be entitled History of the Aircraft Gas Turbine Engine in the United States. In this part, I will outline a series of Tasks which will encompass both my research into the history of the AGTE and my preparation of initial manuscript drafts. I will first propose an historical thesis and research model to be used in my research of the AGTE. Then I will propose a list of the engines to be used as technology advancement examples. Finally, I will outline the technical approach that I propose for my research. This technical approach will serve as the common methodology running through the ongoing series of Tasks, which I will present as the final item at the end of this report.

2. HISTORICAL SOURCES SURVEY OF THE AIRCRAFT GAS TURBINE ENGINE

It is the purpose of this portion of the report to document a survey of historical sources of aircraft gas turbine engine history in the United States. This survey was conducted from September 1987 to July 1988. This report contains two major components. The first major component is a summary of investigations into primary and secondary historical sources and resources of aircraft gas turbine engine (hereafter AGTE) history. The second component consists of the bibliographies generated by that survey of historical sources and resources.

There are two published sources that were the starting points of my research into AGTE history. The first is Development of Aircraft Engines by Robert Schlaifer, published as a Harvard Business School study in 1949. This source remains, despite its early date, the only comprehensive source on the relationship of the government to the aircraft engine industry. This germane work has not, however, been updated since. The second major source is The Origins of the Turbojet Revolution by Edward W. Constant. Constant not only provided a history of the technologies leading up the development of the turbojet, but he also provided a theoretical framework for understanding the technological and societal impetus driving the development of the AGTE. Constant ends his excellent work, however, with the close of World War II.

After an initial bibliographical survey of the field, I was surprised to learn, these two fine efforts notwithstanding, that there have been no other efforts to examine the history of the AGTE on an industry-wide basis after 1949. Although there have been several company histories and at least one aircraft engine encyclopedia published, no historian has attempted to trace the history of the aircraft gas turbine through its development to the present. This initial conclusion has been borne out by my subsequent bibliographic research.

2.1 Search Methodology.

There were several steps in my approach to discovering AGTE sources. The first step was to consider the potential scope of my historical inquiry. My goal, as developed by the Turbine Engine Division of the Air Force's Aero Propulsion and Power Laboratory, was to research the history of the AGTE in the United States. This would mean working from a historical time-frame of roughly 1929 to as far forward as possible (based upon the historical material that I found). The assistance of Marvin

Stibich, the Technical Area Manager of the Compressor Research Group, Technology Branch, Turbine Engine Division, was invaluable in helping me set the scope of the project and establishing search criteria. One of the project research parameters was to draw upon foreign sources only to the extent that these sources shed light upon American developments or influenced American developments. I narrowed down the scope quickly by deciding not to cover ramjets, but only turbojets, turboshafts, and turbofans. Another project parameter was that I draw my search material from only unclassified or nonproprietary sources. Although these parameters were to have a significant impact upon my research, there were other research methodology considerations as well.

The second step in my search methodology was to identify the documents and information desired. I also undertook to identify oral history sources to supplement or corroborate the written sources. These sources have not been identified in this bibliography, but have instead been integrated into my research files for use during the appropriate phase on my research. The second step was to identify potential sources of primary and secondary historical information. I determined that the best single source for books on AGTE history was the Library of Congress. Basic bibliographic searches there were complemented by bibliographic searches at Wright State University in Dayton, Ohio, and at Ohio State University in Columbus, Ohio.

2.1.1 Air Force. Periodical searches were conducted at Ohio State University and the Air Force History Office at Bolling Air Force Base in Maryland. Major sources for periodical searches were the Reader's Guide to Periodical Literature, and at the Air Force History Office, the Air University Library Index to Military Periodicals. Citations in the bibliography were drawn from 130 periodicals.

The search for government documents had to be addressed at several different levels. An important initial source for accessing the Air Force's documentary sources was United States Air Force History: A Guide to Documentary Sources compiled by Lawrence J. Paszek. I went through the Air Force's records management system from the Laboratory level through the Division and to the Command levels, conducting searches in both the Air Force Systems Command and the Air Force Logistics Command archives. I went to the Air Force History Office to work in their databases, particularly the Annual Department of Defense Bibliography of Logistics Studies and Related Documents and Air University Abstracts of Research Reports. Both proved to be very useful in my searches. I found some excellent theses in the directory of theses written by students at the Air Force Institute of Technology (AFIT).

2.1.2 Navy. Before I commenced my research visits to search for Navy AGTE documentation I had a series of discussions with A. S. "Butch" Atkinson. Mr. Atkinson is a former engineer in the Navy's propulsion establishment. These discussions proved very fruitful in several ways. Not only did Mr. Atkinson give me an excellent perspective on Navy propulsion history, but he agreed to survey some of his former associates and acquaintances in the Navy propulsion establishment to see whether there existed any potential oral history sources within that Navy propulsion fraternity. That survey provoked a wide response of potential sources with historical perspectives on key AGTEs developed in the United States.

To determine the location of potential sources of Navy AGTE history, I visited the Center for Naval History and the Naval Aviation History Office. I surveyed back issues as well as the index of Naval Aviation News, a formerly monthly, now bimonthly publication, dating back to 1917. I also examined the finding aids to the Bureau of Aeronautics Technical Reports Index. This index, although confidential, could prove to be an excellent source of primary historical data if declassified. Dr. William Armstrong, a NavAir historian, provided some key assistance in helping me work my way

through the Navy's history offices. Finally, a visit to the Naval Aviation Museum in Pensacola, Florida, and its Director, Captain Robert Rasmussen, was very helpful.

2.1.3 Army. To research the Army's role in AGTE development, I first talked to Donald D. Weidhuner, the former "dean" of the Army's propulsion establishment and now an engineering consultant. Mr. Weidhuner gave me an invaluable perspective on Army propulsion history. I then visited the Army's propulsion establishment to talk to the engineers directly. The US Army Aviation Research and Technology Activity is the organization responsible for directing the Army's propulsion research and development. Mr. Henry Morrow of the Activity's Aviation Applied Technology Directorate was very helpful in bringing me up to date on Army propulsion R&D.

2.1.4 NASA/Government Agencies. A trip to the NASA History Office in Washington and a chat with their archivist Lee Saegesser yielded several excellent clipping files that I was granted permission to copy. I also made research trips to the DARPA Archives at Battelle-Columbus to talk to their archivist Ed Westbrooks and to the Smithsonian's National Air and Space Museum (NASM) in Washington, D.C. to talk to Rick Leyes, the Engine historian in their Aeronautical Research Office. NASM's Aircraft Engines in Museums Around the World proved to be an excellent resource in tracking down specific AGTEs on my various research trips. Mr. John Taylor, Military Records Branch Archivist of the National Archives, was especially helpful in explaining the records retirement process of the government.

2.1.5 Industry. To search for AGTE history at the corporate level, I had to visit the companies that are still in the business to ascertain for myself what historical material existed at the various companies. I found a wide degree of variance in the amount and quality of historical material available. Some companies had a well-organized archive of historical material, while some companies had a wealth of unorganized material, and other companies had little if any material gathered together at all. Research visits were made to the following companies:

(a) Garrett Turbine Engine Company

(b) Allison Gas Turbine Division of General Motors Corporation
(c) Pratt and Whitney Government Products Division of United Technologies Corporation
(d) Pratt and Whitney Commercial Products Division of United Technologies Corporation
(e) Textron-Lycoming
(f) Williams International Corporation
(g) General Electric Aircraft Engines Company
(h) Solar Turbines, Incorporated
(i) Sundstrand Turbomach
(j) Boeing Corporation
(k) Lockheed Aeronautical Systems Company
(l) Rand Corporation

Due to the proprietary nature of some of the documents uncovered in the historical sources survey, I have included in this inventory only those published newspaper or periodical sources found at the aircraft engine companies that are also available to the general public. A great deal of source material (such as descriptions of files and listings of documents provided to me by corporate archivists) have been incorporated into my research notes and not listed in this bibliography. This was at the

request of individual archivists and historians, who, although they did not wish to hinder my research in any way, were not comfortable in seeing their collection of catalogues, inventories, and listings made public.

Since many of the past giants of the turbine engine business have either gone out of business entirely (such as Curtiss-Wright and Frederic Flader), or have ceased development of AGTEs (such as Westinghouse and Boeing), I realized that I must therefore rely on oral history sources to complement the scarcity of historical documentation available on the work of these companies. My list of such oral history sources is not extensive and should prove to be of great value to my research.

2.1.6 Museums. Many aviation museums have AGTEs in their collections and there are many outstanding engines displayed, but the amount of background documentation on the engines themselves is negligible. This was no doubt due to the fact that the engines were donated by the manufacturers to the museum and that the receivers of such largesse were in no position to insist on full documentation accompanying such donations. These facilities do, however, provide excellent example cutaways of specific engines. Specific museums visited include:

(a) Air Force Museum
(b) National Air and Space Museum of the Smithsonian
(c) San Diego Aerospace Museum
(d) U.S. Navy Memorial Museum
(e) Bradley Air Museum
(f) Naval Aviation Museum
(g) General Electric Engine Museum
(h) Marine Corps Aviation Museum
(i) U.S. Army Transportation Museum

Citations of individual reports and other documents found have not been included in this bibliography, but have been incorporated into my research files for use at the appropriate stage in my research.

2.1.7 Technical Societies. The final potential source of AGTE historical documentation are the AGTE professional societies, such as the American Society of Mechanical Engineers International Gas Turbine Institute (ASME-IGTI), the Society of Automotive Engineers (SAE), and American Institute of Aeronautics and Astronautics (AIAA). I compiled a list of references from these organizations as they appeared in the various bibliographic databases, such as the Directory of ASME Gas Turbine Technical Papers of the American Society of Mechanical Engineers International Gas Turbine Institute. Attending the 1987 SAE Aerospace Vehicle Conference enabled me to attend the fascinating session on "Historical Events in Gas Turbine Propulsion," where I listened to some of the most influential people in the field discuss some aspects of the history of AGTE research and development.

2.2 Bibliographic Search Criteria.

Before commencing a bibliographic search of the existing published materials, I developed a bibliographic search criteria. There exists a large body of periodical material on the AGTE, and it was necessary to cut through to the historical heart of the material. Even with this criteria, it was difficult to determine the potential historical usefulness of an article by simply looking at the title (without reading it).

The first and most obvious historical elements that I looked for were those references that were historical narratives, either written by or about those pioneers of the AGTE. Dr. Hans von Ohain, and Sir Frank Whittle were the two main subjects of this aspect of the search, although others such as Jendrassik in Hungary, Wagner in Germany, Nathan Price in the United States, and others were also on my list. As you can see, my list of pioneers was not restricted to the United States alone. I believe that the US owes a great debt to those pioneers from other countries that broke the initial ground in AGTE research.

Second on the list of criteria were those articles that described particular AGTE technological developments historically, or that provided historical descriptions of AGTE development programs. The various histories of companies that developed AGTEs, such as General Electric's Seven Decades of Progress, and others, are examples of this type of source.

The next criteria was to identify those sources that provided a description of the state of AGTE development at any one point in time. These were often comparisons of British and American or European and American avenues of approach to solving AGTE development problems, or, comparisons of different engines designed to address the same requirement.

Next on the criteria was to identify those publications that described individual American-developed aircraft gas turbine engines. Many of the American engines were described and analyzed by the trade publications shortly after being introduced into service by either the Air Force or an airline. Of particular interest were the British or European reviews of American products. Many of the publications devoted to aviation published annual listings of the aircraft gas turbine engines then in service. These listings were often accompanied by data on AGTE utilization in the U.S.

I decided to examine selected themes in the history of the AGTE in the United States. These themes seemed to recur in the periodical literature on the AGTE. Examples of some of these themes are:

(a) Competition for development resources between the piston engine and the aircraft gas turbine engine.
(b) Competitive development of the centrifugal and axial compressor for AGTE application.
(c) Relative merits of the turbojet, turboprop, and turbofan for differing aviation requirements.
(d) Competition for sales between American and foreign AGTE manufacturers.
(e) The question of technology transfer between American and foreign companies.

There were several trends in AGTE development that have developed along with the engines themselves. Computer analysis of AGTE materials, component development, production and performance prediction is a trend that dramatically influenced the research and development of the AGTE. Cost analysis, life-cycle analysis, and other logistical analysis have been spurred by computer enhancement. Finally, the ongoing debate over the impact of competition within the AGTE development community was a trend that I decided to survey.

2.3 Oral History Source Criteria.

As with the bibliographic criteria, I developed a ranking method for determining the potential value of the oral history narrators that I found. The most important potential sources of oral history are the two inventors of the aircraft gas turbine engine, Dr. Hans von Ohain and Sir Frank Whittle, both of whom are still alive and living in the United States. Another pioneer in AGTE development is Dr. Anselm Franz, who, with former members of his Junkers design team came to this country and developed the Textron-Lycoming center of turbojet, turboprop, and turboshaft research and development. These were the most valuable of my potential sources.

The second, but also very important tier of potential oral history narrators are those primary designers and leaders of the design and development teams of the first American efforts at AGTE development. Those members of the General Electric, Lockheed, Westinghouse, Solar, and the other initial corporate research and design teams will be very valuable for information. Dr. Sam B. Williams, Nathan Price, Helmut Schelp, and other important contributors to AGTE development are in this group.

The third tier of potential oral history narrators are those engineers and scientists who have made significant contributions to AGTE development advancement. Leaders of corporations such as Gerhard Neumann, William Brown, Heinz Moellman, Jack Curry, Peter Tramm, J.P. Frignac, and others are important sources for AGTE history. The government side of the AGTE development story must also be told in any history of the technology. Individuals such as A.S. Atkinson of the Navy, Ernest C. Simpson of the Air Force, and Don Weidhuner of the Army are valuable sources of AGTE history (although Simpson of the Air Force has passed away, his end-of-tour report The Last Great Act of Defiance is still a valuable source of behind-the-Scenes history).

Oral history alone cannot tell the whole story of the development of the aircraft gas turbine engine in the United States, but it can provide the necessary corroborative evidence to verify the written record, and it can tell the "human" story of the development of this remarkable technology. After all, research, design, and development are accomplished by people, and their stories, although distorted by time, events, and emotions, are valuable additions to the database with which the historian examines the past.

In the interests of protecting the privacy of those individuals who have agreed to be interviewed, I have not listed their names in this bibliography. The names of specific individuals have been cross-referenced with the applicable engines in my research files. Anyone with a legitimate research interest in aircraft gas turbine engine history can contact me directly to obtain specific research leads.

2.4 Conclusions.

As you will see from the following bibliography, I have found a great many secondary sources on aircraft gas turbine engine history. The number of primary sources, however, is limited. The primary sources of AGTE history are the reports of the inventors and developers of the technology, written as the research and development took place. Much of this material is buried deep within the recesses of the governmental systems of records retention and archives. Digging through the morass of material to uncover a comprehensive history of the entire aircraft gas turbine engine industry is impossible to accomplish in any one project due to several reasons.

The first reason is that there hasn't been enough scholarly research into the records of AGTE development to determine precisely how much contract records and other corporate historical material

exists. Backtracking through the several federal agencies responsible for monitoring and funding AGTE research and development would alone require a large scale research effort.

The companies responsible for research, design and development of aircraft gas turbine engines have done so for the most part under government contract. What material that has not been given over to the government at the end of a particular contract effort is jealously guarded by the companies due to the tremendously competitive nature of the business.

Much of the history generated by the companies is, to say the least, only reflective of that particular company's historical contributions at the expense of academic, government, and/or other corporate contributions to the technology. They are good publicity for the company, but hardly reflective of historical reality as far as the whole of AGTE history is concerned.

Another difficulty in attempting a comprehensive history of the aircraft gas turbine engine is that the astonishing growth of this technology has given impetus to the development of many now standard turbojet derivatives, such as the turboprop, turboshaft, and turbofan. There have been many not-so-standard derivatives as well, such as the ramjet, turboramjet, turborocket, the turboaccelerator, and other exotic variants. Derivatives of aircraft gas turbine engine technology are now being utilized as powerplants by suppliers of ground power, shipbuilders, tank manufacturers, and others.

Each of these derivatives have both resulted from and provided impetus for an astounding degree of gas turbine component development. Each of the major components of the aircraft gas turbine engine (or any other gas turbine engine), the compressor, combustor, turbine, nozzle, and controls have themselves been the focus of major research, design, and development programs. What has resulted is a huge mass of historical, engineering, and scientific data. The advent of the computer, which has enjoyed a similar spectacular technological growth in about the same time-frame as the AGTE, has provided a heretofore unheard-of ability to analyze, model, and/or predict the performance of the AGTE. This has again resulted in unparalleled research advances in component design, construction, and integration. This has, in turn, generated masses of computerized data, adding to the ever-growing mass of data to be surveyed (at least) by the historical researcher.

The question became "how does one reduce this historical examination of the aircraft gas turbine engine to manageable proportions?" The solution which was proposed to me by the engineers in the Turbine Engine Division of the Air Force Aero Propulsion Laboratory was to examine the history of the AGTE by looking at the design and development of the engines that exemplified significant technological achievements that have shaped the development of the technology as a whole. This would dramatically reduce the scope of my research while providing a balanced view of the entire field of AGTE technological growth. I would describe the development of specific engines, using available historical documentation corroborated by oral history interviewing, while also providing a narrative history of the growth of the technology as a whole.

Through a series of discussions with Dr. Walter O'Brien, Professor of Mechanical Engineering at Virginia Polytechnic Institute and State University, and former Chairman of the ASME's Gas Turbine Committee, we developed a thesis and research model that took the "example engines" idea and fit it into a conceptual framework of "threat/opportunity leading to response, limited by boundary conditions." This thesis is detailed in the second part of this report.

While I will give AGTE research, design, and development credit to those foreign engine establishments where credit is due, this will be a history of American AGTE development. The AGTE establishment in the United States owes a large technological debt to those in Great Britain and

Germany who pioneered the development of the AGTE. This pioneering work must be acknowledged by any history of the technology. Major engine examples, however, will be drawn from American AGTE development.

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3.2 Books. Apart from the two works mentioned in the introduction to this report, the books listed here are mostly secondary sources. Very few are histories of the AGTE. Most of these sources are specific to the AGTE, although some are specific to one or more historical or technical aspects of AGTE history. Some are identified by a Library of Congress (LOC) call number. These books have not been surveyed for the historical material that they may contain, but rather are listed as a starting point for historical research. Other references discovered during the course of my research will be added to this bibliography.

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4. OUTLINE FOR PROPOSED HISTORY OF THE AIRCRAFT GAS TURBINE IN THE UNITED STATES

4.1 Thesis.

My research model, or thesis, for the development of The History of the Aircraft Gas Turbine Engine in the United States, will be that the historical development of the aircraft gas turbine engine has been characterized by a pattern of technological response to outside stimuli controlled by specific limitations upon that response. This historical model can be compared to the mathematical equation $Y(i)= a(i)(X)$,
where

Y(i)= Dependent Response Variable/Factors

a(i)= Factors relating response to independent variables

X= X1 or X2, Independent Variables/Factors (threats or opportunities)

Where i = many possible multipliers and/or responses to X.

In the historical development of the AGTE, the independent input variables/factors have been either X1) hostile threats to society, or X2) economic opportunities.

The response [Y] or responses [Y(i)] to these independent input variables are the many elements of the programs and methodologies that lead to specific AGTE developments, the whole R&D process representing specific responses to the input independent variables (X) (threat/opportunity).

The factors [a(i)] govern the response to the perceived "X". The range of possible "magnitudes" of the factors depend upon boundary limitations/factors, i.e., those considerations that represent limitations or opportunities to address the independent input variables (X). Among boundary limitations/factors are A) materials, B) costs, C) theoretical understanding, D) facilities, E) leadership (or national will), and F) knowledge (or analytical ability).

The range of these boundary limitations/factors can and have been influenced by specific multipliers such as: A) national will in time of crisis, and B) the advent of technological impactors such as computers and specific materials technology advances.

This research model will be applied to my historical investigation of the development of AGTE technology. I will look at each engine, trying to identify the threat or opportunity which led to its consideration, and the boundary limitations/factors which influenced the response. The description of each engine will be presented in this light.

Here are the AGTEs that resulted from the responses of the turbine engine technology community to the independent variables outlined above. The underlined topics represent historical subject or chapter headings. Following some of the topic groupings are potential research questions to be investigated during my research.

4.2 Proposed Chapters.

4.2.1 Proposed Chapter One. The Pioneers of the AGTE: Dreamers, Inventors, and Engineers. Hans von Ohain, Sir Frank Whittle, Nathan Price, Jendrassik, the Russians.

4.2.2 Proposed Chapter Two. The Early Years of the AGTE in the United States: General Electric and the British.

(a) GE I-A -- General Electric version of Whittle's engine.
(b) J31 (GE I-16) General Electric -- first American turbojet.
(c) J33 (GE I-40) -- General Electric centrifugal compressor AGTE--first American mass-production (by Allison) AGTE.

4.2.3 Proposed Chapter Three. Westinghouse Tries and Leaves.

(a) J30 Westinghouse AGTE, first "all-American" turbojet, first Navy operational engine, and first operational engine with axial compressor.
(b) J46 Westinghouse engine, first Navy operational AGTE with an afterburner.
(c) J54 Westinghouse, only military-qualified engine developed as a private venture.

4.2.4 Proposed Chapter Four. General Electric Applies New Ideas, American Technology.

(a) J35 (TG-180) first General Electric axial compressor AGTE.
(b) J47 GE AGTE with turbine cooling, most-produced AGTE in history.

Research Question: Was the J47 an outgrowth of the J35, with turbine cooling?

4.2.5 Proposed Chapter Five. Pratt & Whitney Acknowledges the Existence of the AGTE.

(a) J42 (JT6B) First Pratt & Whitney operational AGTE-manufactured under license from RR (Derwent).
(b) J48 (JT7) P&W-manufactured under license from RR (Tay).
(c) J52 Pratt & Whitney, basis for the highly sucessful JT8D engine.

Research Question: If this engine was dual-spool, then this gets the credit for the J57 listed below, and is the beginning of the modern era of P&W compressors?

4.2.6 Proposed Chapter Six. Multiple Spools.

(a) J57 Pratt & Whitney twin-spool concept, and titanium. The beginning of the modern era for P&W, represents P&W development of the ability to build and operate very high pressure ratio compressors in AGTE.
(b) TF33 first Pratt & Whitney turbofan, forerunner of JT3D commercial AGTE, J57 engine with a fan attached.

Research Question: If the J57 was the first to use titanium, this is a very important milestone.

4.2.7 Proposed Chapter Seven. AGTEs Power Helicopters.

(a) T53 turboshaft for helicopters, by Textron-Lycoming, developed to be "universal application" AGTE.
(b) T55 Textron-Lycoming helicopter engine.
(c) T58 General Electric turboshaft engine. Response to Lycoming, and a big success.
(d) T64 General Electric turboshaft engine.
(e) T700 General Electric turboshaft engine, used in Blackhawk, Apache, and Seahawk helos.

4.2.8 Proposed Chapter Eight. AGTEs Power Turboprops. The T56, an Allison turboprop AGTE, was an extensively used military and commercial turboprop. This possibly could be considered a very practical and commercial response to a need, using known technology in a conservative way.

4.2.9 Proposed Chapter Nine. Fascinating Diversions -- Possibly a Key to the Future.

(a) J58 Pratt & Whitney, first mach-3 turbojet, high-bypass cycle, use of titanium.
(b) J93 General Electric's B-70 supersonic cruise engine.

Research Questions: What were the technological roots of the J58? Could the roots be the J57?

4.2.10 Proposed Chapter Ten. Variable Compressor Vanes.

(a) J79 General Electric variable-stator AGTE, roots of the modern GE high pressure ratio compressor technology.
(b) TF34 General Electric, first operational Navy high bypass turbofan engine.

Research Question: Is the TF34 a J79 with a fan attached?

4.2.11 Proposed Chapter Eleven. Ducted Augmented Turbofan Engines.

(a) TF30 Pratt & Whitney, first operational afterburning turbofan engine. It does represent the American prototype and initially sucessful engine of the ducted fan, afterburning, interceptor/high performance engine concept which is used in the F-14, and F-111 aircraft [P&W F100, GE F110, GE F101(?)]
(b) F100 Pratt & Whitney, high performance ducted augmented turbofan.
(c) F110 General Electric high performance ducted augmented turbofan.
(d) F404 General Electric high performance ducted augmented turbofan for F-18.

Research Questions: Where does the core of the TF30 engine come from? Was this the first result of the building-block concept of Cliff Simpson, or does it have a developmental relationship to the J52 and J57?

4.2.12 Proposed Chapter Twelve. Very High Bypass Turbofan Engines.

(a) TF39 General Electric high-bypass turbofan, designed for the C-5A.
(b) CF6 and other GE high bypass civilian engines that resulted from the TF39.
(c) JT9D P&W civilian engine, could be said to be a competitive response to GE.

Research Questions: Did the TF39 utilize the building-block concept developed by Cliff Simpson? Does the TF39 represent the beginning of very-high bypass turbofan engine technology?

4.2.13 Proposed Chapter Thirteen. Life Engines; Vertical Take-off and Landing AGTEs. F402: Rolls-Royce Pegasus engine for the Harrier.

4.2.14 Proposed Chapter Fourteen. Special AGTE Applications.

(a) T76 (TPE331) Garrett AGTE designed from APU, no government funds used in design and development.
(b) F107 Williams International cruise missile AGTE.
(c) J402 Teledyne CAE, first operational engine developed exclusively for an unmanned vehicle.

4.3 List of Boundary Condition Factors to be Explored.

Here are the boundary condition factors which determined the factors relating the independent variables to the response. These factors impacted the entire spectrum of AGTE technology development. These factors will also be investigated throughout the period of my research.

(a) The role of computers in AGTE development.
(b) The question of competition in AGTE development.
(c) Cost and Cost Effectiveness in AGTE development.
(d) Technology transfer and AGTE development.
(e) The role of government in AGTE development.
    - govt. as sponsors of the technology
    - role of the SAB and von Karman
(f) The role of universities in AGTE development.
(g) The role of NACA in AGTE development.
(h) The role NASA in AGTE development.
(i) The role of the development of fundamental and applied science in AGTE development.
    - universities
    - companies/think tanks
    - government labs
(j) Environmental constraints on AGTE development.

4.4 Some of the Important People in the History of the AGTE.

I would like to include some individuals whom I feel contributed in significant ways to the development of the AGTE.

Hans von Ohain
Frank Whittle
Von Karman
Anselm Franz
Mel Hartmann (NASA Lewis)
Gerhard Neumann
William Brown (P&W)
Donald Weidhuner
Leroy Smith (GE)

4.5 Technical Approach.

The UES principal investigator proposes a Task-order approach to research and writing of the history. Specific research topics would be identified in accordance with the proposed outline of work, and each research topic would be approached in accordance with a specific research methodology. Each task would include between one and four research topics, following the schedule set forth in the proposed outline.

The research topics would be developed as a historical research element or technical element of the task. Each historical research element would follow the following procedure:

4.5.1 Step 1. References research:

(a) Research appropriate articles in AGTE Bibliography.
(b) Gather together appropriate books for research, generate a list of secondary sources.

4.5.2 Step 2. Preliminary research:

(a) Establish timeframe for development of research chronology.
(b) Determine interview approach to oral history sources.
(c) First meeting with appropriate consultants.
(d) Revise chronology and methodology if necessary.
(e) Set up on-site visit schedule.

4.5.3 Step 3. On-site research.

(a) Interviews with oral history sources, generate interview outlines.
(b) Conduct on-site research, generate initial chapter outline.

4.5.4 Step 4. First writing phase.

(a) Revise initial chapter outline with any new material.
(b) Generate first chapter draft.
(c) Second meeting with consultants, if necessary.

The steps necessary to complete any technical elements of the Task will be identified in each Task as required.

4.6 Proposed Task Schedule for History of the Aircraft Gas Turbine in the United States.

4.6.1 Task I. Pioneers of the AGTE: Part 1. Consists of four elements; three historical research element and one technical research element.

Phase One:

(a) Whittle historical research element.
(b) Von Ohain historical research element.
(c) American historical research element.
(d) Technical element (preparation of a multi-media presentation of the history of the AGTE).

4.6.2 Task II. Pioneers of the AGTE: Part 2. Consists of two historical research elements and one technical element:

(a) von Ohain historical research element.
(b) American historical research element.
(c) AGTE History Video Edit technical element.

4.6.3 Task III. The Early Years of the AGTE in America. Consists of three historical research elements:

(a) GE 1-A historical research element.
(b) GE J31 (GE I-16) historical research element.
(c) GE J33 (GE I-40) historical research element.

4.6.4 Task IV. Westinghouse Tries and Leaves. Consists of three historical research elements:

(a) Westinghouse J30 historical research element.
(b) Westinghouse J46 historical research element.
(c) Westinghouse J54 historical research element.

4.6.5 Task V. This is a two phased task. The first phase would consist of the chapter entitled General Electric Applies New Ideas, American Technology. This phase would consist of two historical research elements.

Phase One

(a) GE J35 (TG-180) historical research element.
(b) GE J47 historical research element.

The second phase would consist of the chapter entitled Pratt & Whitney Acknowledges the Existence of the AGTE. This phase would consist of three historical research elements.

Phase Two

(a) P&W J42 (JT6B) historical research element.
(b) P&W J48 (JT7) historical research element.
(c) P&W J52 historical research element.

*U.S.Government Printing Office: 1989 —648-056/04420